AD-A188 473 MAGNETIC TRAPPING OF NEUTRAL ATOMS(U) MASSACHUSETTS INST OF TECH CAMBRIDGE RESEARCH LAB OF ELECTRONICS V BAGNATO ET AL. JAN 87 N00014-83-K-0695 1/1

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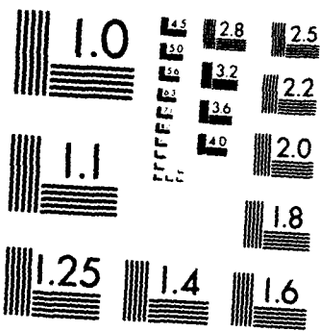

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Work by D.E. Pritchard and his collaborators is summarized here.

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lecular potential than either the rotation or translation; the result is little change in the vibration. At high j, the molecule rotates substantially during a vibrational period, yielding a sudden force on the vibrator that can produce large changes in the vibration. The correlation of Δv and Δj results from a subtle interaction of the vibrational and rotational phases at the instant of maximum force. Finally, at very low velocity, the molecule can collide several times with the atom due to the rapid rotation, resulting in an enhancement in the above effects and a strengthening of V $\longleftrightarrow$R transfer. Each of these effects can be seen in Figure 22.11, a plot of some of the dyanmical variables versus time through one collision. The top two graphs (of v and j) show that at each step through the collision Δv and Δj are anti-correlated and that each "collisionette" of an end of the molecule with the atom builds on the others, resulting in a large net transfer.

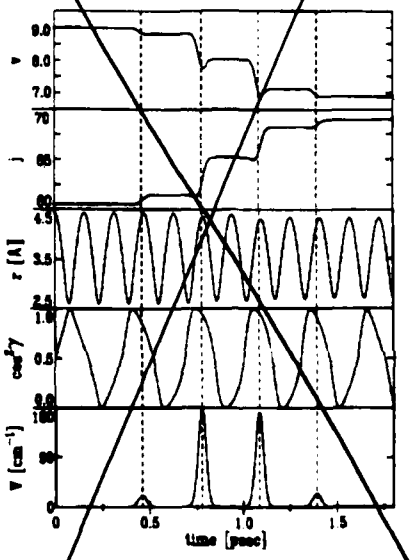

Figure 22.11. : Plot of the vibrational action (v), the rotational action (j), the internuclear separation (r), cosine of the rotational angle (γ) and the intermolecular interaction energy (V) as functions of time through a single, simple collision. Note the peaks in $V(t)$ corresponding to "collisionettes."

Because this model has been successful, we can use it to make predictions about as yet unobserved classical effects. A good example of such an effect is the collisional reorientation of the molecular rotation axis. For collisions which are either rotationally inelastic or not, the *direction* of the angular momentum vector $\vec{j}$ can be altered. Utilizing the polarization of the incident and fluorescent light, the reorientation cross section can be measured experimentally. Classical trajectory calculations can readily make predictions about the amount of reorientation and the cross section for it. In addition, trajectories naturally give the velocity dependence of this process which can also be measured experimentally using the Doppler shift.

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22.5 Magnetic Trapping of Neutral Atoms

U.S. Navy - Office of Naval Research (Contract N00014-83-K-0695)

Vanderlei Bagnato, Gregory Lafyatis, Alexander Martin, Eric Raab, Riyad Ahmad-Bitar, David E. Pritchard

We are working on a program to slow, trap and cool neutral atoms. Laser light is used to slow and cool atoms and magnetic forces are used to trap them. Ultimately we hope to be able to trap atoms for days and cool them to temperatures on the order of 10^{-6}K In addition to the interesting scientific and technical challenges involved in trapping and cooling atoms, we hope to open several new lines of investigation with these cooled atoms. Cold trapped atoms constitute a good system for studying collective phenomena such as Bose condensation, low energy - Na and Na – Na*, and coherent optical effects (the deBroglie wavelength can exceed the optical wavelength). They also offer opportunities for performing ultra-high resolution spectroscopy and are extremely promising candidates for a new generation of frequency standards.

In 1986 we completed construction of our neutral trap apparatus and began doing experiments with it. Our first successful run has advanced the state of the neutral atom slowing and trapping art by several orders of magnitude. We have continuously stopped atoms with laser light, continuously loaded them into our 0.1K deep superconducting magnetic trap, and held them for up to six minutes. Continuous trap loading is an important advance over previous pulsed loading [1] schemes because it permits the accumulation of large numbers of atoms in the trap and, hopefully, enables the study of collective phenomena in the trap. Our trap, though somewhat more complicated in design and construction than the two previously reported atom traps [2] has the advantage of a uniform magnetic field region in its center in which optical pumping and precision spectroscopy of cooled atoms may be undertaken. Fluorescence from trapped atoms has been observed for 10 sec with intense illumination. Finally, we have observed trapping decay times of two minutes -- two orders of magnitude better than the previously reported traps. It is our expectation that we will soon see trapping times of hours, or perhaps days, giving us sufficient time to perform experiments on the trapped atoms. We are now in a position to

move neutral traps from the status of laboratory curiosities to that of powerful tools for new research in physics.

Figure 22.12 is a schematic of our experiment. Superconducting magnets were designed and constructed to provide the necessary field to slow and trap neutral atoms. Na atoms from a 500°C oven are slowed, in two stages, by laser beams propagating counter to the atomic beam. A tapered magnetic field creates a Zeeman shift in the atomic levels and compensate for the changing Doppler shift of the atoms as they slow. The second laser beam is retroflected and cools the atoms to milliKelvin temperatures near the trap's center. We trap atoms in states whose electron spin is parallel to the magnetic field -- these atoms experience a force towards regions of weak field (c.f. Stern-Gerlach experiment).The field minimum located at the center of our trapping magnets constitutes a 0.12K deep trap for atoms. Photodiodes located at several places within the apparatus are used to detect fluorescence from the slowing and trapped atoms.

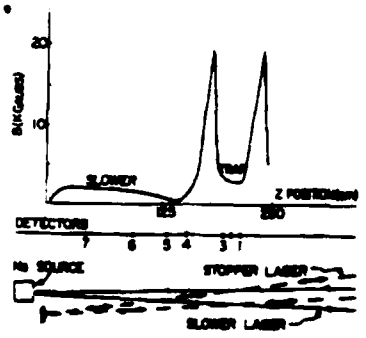

Figure 22.12. : Schematic of the experiment. The upper figure shows the magnetic field profile, below the positions of the detectors are shown, and at the bottom of the atomic source and laser configurations.

Figure 22.13 is a composite of several runs in which the trap lifetime was measured by recording the fluorescence from trapped atoms. The sequence used to make up Figure 22.13 was: lasers on to fill the trap, lasers off for a (variable) period of time, second laser turned back on to probe the remaining atoms. Our diagnostics for those initial measurements were coarse and presently we can only make a lower limit estimate in the number of atoms in the trap: $\approx 10^8$. There may well be two orders of magnitude more trapped atoms which have inadvertently decayed to another hyperfine state which is well out of resonance with the laser light. This inadvertent optical pumping should enable us to perform RF resonance on the trapped atoms. In the future we hope to accumulate more atoms, study Doppler cooling of the trapped atoms (expected to achieve submilliKelvin temperatures), investigate "cyclic" cooling of atoms [3] (projected to achieve temperatures near $1\mu K$) and use RF resonance both to study the trapped atoms and possibly to develop a frequency standard.

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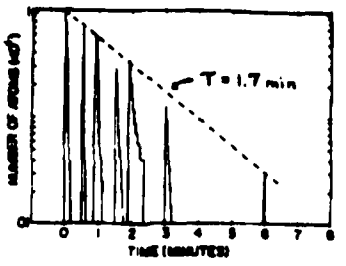

Figure 22.13. : Result of several runs. Each curve is the result of charging the trap, blocking both laser beams, and after the indicated time, turning back on the stopping beam and recording the fluorescence from trapped atoms.

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22.6 Precision Mass Spectroscopy of Ions

National Science Foundation (Grant CHE 84-21392)
Joint Services Electronics Program (Contract DAALO3-86-K-0002)

Eric Cornell, Robert W. Flanagan, Greg P. Lafyatis, David E. Pritchard, Robert M. Weisskoff

We are developing an experiment to determine the mass of individual atomic and molecular ions at precisions of 10^{-11}. This technique will allow us to do a variety of experiments which address issues of both fundamental and applied physics:

- The $^3H^+ - {}^3H_e^+$ mass difference is an important parameter in ongoing experiments to measure the electron neutrino rest mass.
- Excitation and binding energies of typical atomic and molecular ions might be studied by "weighing" the small increase in energy: $\Delta m = E_{bind} / c^2$.
- Experiments that weigh γ-rays can be used in a new method to determine N_A, the Avogadro constant.
- Traditional applications of mass spectroscopy should benefit from the several orders of magnitude improvement in both accuracy and sensitivity our approach offers over conventional techniques.

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